PATENT SPECIFICATION

(11) 1 449 852

1449852

(21) Application No. 37932/73 (22) Filed 10 Aug. 1973

(61) Patent of Addition to No. 1376622 dated 31 Jan. 1972

(23) Complete Specification filed 8 Aug. 1974

(44) Complete Specification published 15 Sept. 1976

(51) INT CL² G05D 16/00 F04D 15/00

(52) Index at acceptance

G3R 110X 112B 112X 116 33D2R 35D 4 7Q 7R 8R 9A 9B 9F 9H X

F1C 2J1A 2J1B 2J2C1

(19)

(54) IMPROVEMENTS RELATING TO THE CONTROL OF FLUID PUMPS

(71) I, JOHN DAVID COPPEN of The Ridgeway, Iver, Buckinghamshire, England, a British subject, do hereby declare the invention for which I pray that a patent may be granted to me and the method by which it is to be performed to be particularly described in and by the following statement: —

This invention relates to a fluid pump unit control system and to a fluid pump unit comprising a fluid pump, a drive therefor and a control system for the unit.

Like the invention disclosed in the complete specification of my British Patent 1,376,622, on which the present invention is an improvement, the present invention is particularly, though not exclusively, applicable to the control of water pumps in fire fighting appliances and is concerned with maintaining the delivery of fluid from the pump at a substantially constant delivery pressure to the extent to which this can be done, having regard to the supply of fluid to the pump, and in particular taking the inlet pressure of the pump into account, in order to prevent "overrunning" the available fluid supply which can lead to cavitation in the pump and/or the collapse of collapsible (or so-called "soft") hoses which are frequently used to supply the pump.

According to the invention, in a first aspect thereof, a fluid pump unit control system comprises first fluid pressure responsive means for comparing a first fluid pressure with a first reference value thereof and to provide a first signal representing a deviation of the said first fluid pressure from the said first reference value, second fluid pressure responsive means for comparing a second fluid pressure with a second reference value thereof to provide a second signal representing a deviation of the said second fluid pressure from the said second reference value and defining a component of a system output signal, and a regulating device responsive to the said output signal, and tending to maintain the said second fluid pressure at the said second reference value, the said first and second fluid pressure responsive means being so connected that the said second reference value depends on the said deviation of the first fluid pressure.

The said first and second fluid pressure responsive means may each comprise a pressure sensor in the form of a pressure-responsive transducer arranged to produce electrical signals, preferably in the form of voltages, representing the pressure sensed by the senor.

In a system according to the invention, the said first reference value may be defined by a predeterminable and adjustable first set point of the said first fluid pressure responsive means and the said second fluid pressure responsive means may have an adjustable second set point for defining the first fluid pressure dependent second reference value.

In one preferred form of system embodying the invention, the said first and second fluid pressure responsive means each comprise a comparator for comparing the said first and second fluid pressure with the said first and second reference value thereof respectively, the output signals from the comparator of the said second fluid pressure responsive means defining the said system output signal or component thereof, the said regulating device being defined by a speed controller for controlling the speed of a pump drive and having a servo-motor connected to receive the system output signal, and the comparator of the said second fluid pressure responsive means having an input such as to make its output dependent upon the output of the comparator of the said first fluid pressure responsive means.

According to the invention, in a second aspect thereof, in a fluid pump unit comprising a fluid pump and a drive for the pump and having a control system according to the said first aspect of the invention, the said first fluid pressure is defined by the pump inlet pressure, the said second fluid pressure is defined by the pump delivery pressure and the said regulating device is defined by a device for varying a pump parameter which affects the pump delivery pressure.

According to the invention, in a third aspect thereof, in a fire fighting appliance including

a fluid pump unit according to the said second aspect of the invention, the said fluid pump is defined by a water pump and adapted for use with a "soft" (i.e. collapsible) and/or "hard" (i.e. rigid) inlet hose.

Various forms of control system embodying the invention and applied to the control of a fluid pump unit in the form of an internal combustion engine driven centrifugal water pump of a fire fighting appliance will now be described by way of example only, with reference to the accompanying diagrammatic drawings, in which:

Figure 1, which does not show one of the embodiments of the present invention, is a representation of a control system showing some, but not all of the integers of the system of the present invention, purely to assist in the explanation of the latter;

Figure 2 shows one form of embodying the present invention;

Figure 3 shows a first modification of the system of Figure 2;

Figure 4 shows a second modification of the system of Figure 2;

Figure 5 shows a detail of a third modification of, and for incorporation in, the system of Figure 2; and

Figure 6 shows several possible further variations of the system in accordance with the invention.

Referring to Figure 1, a fluid pump unit comprises a fluid pump in the form of a centrifugal water pump 1 having an inlet 42 and a delivery side 43, the pump being driven by an internal combustion engine 3 through a shaft 41.

The control system for the pump unit comprises a first fluid pressure responsive device in the form of a potentiometric pressure transducer 6 and a second fluid pressure responsive device in the form of a similar potentiometric pressure transducer 7. The transducer 6 provides a first input signal to the control system representing the magnitude of the inlet pressure to the pump and the transducer 7 provides a second input signal to the control system representing the magnitude of the delivery pressure of the pump.

First reference means in the form of a pressure-setting potentiometer 14 provides a first reference signal representing a predetermined minimum inlet pressure, and second reference means in the form of a similar pressure-setting potentiometer 17 provides a second reference signal representing a predetermined desired or required delivery pressure.

A first signal comparator 15 is connected to provide a first output or error signal representing any deviation of the magnitude of the actual inlet pressure from that of the minimum inlet pressure set at the potentiometer 14, this output signal being amplifier by an amplifier 40.

A second signal comparator 18 is connected to provide a second output signal representing any deviation of the magnitude of the actual delivery pressure from the required delivery pressure set at the potentiometer 17.

The output from the amplifier 40 being connected to one end of the potentiometer 17, the magnitude of the "required delivery pressure" reference signal provided by the latter is made dependent on the inlet pressure error signal supplied by the comparator 15.

The comparator 18 is connected to, so as to supply its output or error signal defining the system output signal, to means responsive to this signal for varying the pump delivery pressure, the latter means being defined by a servo-motor 4 and its associated servo-motor drive amplifier 44.

The servo-motor 4 is arranged to control the power delivered by the engine 3 for the purpose of accomplishing this variation in pump delivery pressure.

The whole control system is so adjusted that when the inlet pressure falls below the predetermined value, the pump delivery pressure is reduced in dependence on the magnitude of the said inlet pressure to the extent necessary to prevent the pump "over-running" the water supply and thereby causing the collapse of a collapsible inlet hose (if fitted) and/or cavitation in the pump, whilst when the inlet pressure is at or above the said predetermined value, the delivery pressure tends to remain at its said predetermined desired or required value by reason of the control exerted by the servo-motor 4 on the engine speed.

The ends of the elements of the potentiometers of the devices 6, 7, 14, 17 are connected to a common potential *E* which is conveniently "earth". The other ends of the elements of the transducers 6, 7 and that of the potentiometer 14 are connected together to a suitable supply voltage *A*, the other end of the potentiometer 17 being, as already mentioned, connected to the output of the amplifier 40.

The potentiometers 14 and 17 are set by the pump operator for appropriate "minimum inlet pressure" and "required delivery pressure" respectively, to suit the immediate situation.

In operation, when the water supply to the pump 1 is unrestricted, the inlet pressure indicated or monitored by the transducer 6 is higher than that set at the potentiometer 14. Under those conditions the output of the comparator 15 drives the amplifier 40 into saturation such that its output is at or close to the voltage *A*.

If now the delivery pressure monitored or indicated by the transducer 7 is lower than that required, the voltage output of the transducer 7 will be less than that from the potentiometer 17. The output of the com-

parator 18 representing the error between these two voltages will drive the amplifier 40 in such a direction as to cause it to energise the servo-motor 4 in a direction opening the engine throttle. This will cause the pump speed to increase, and thus to increase the pump delivery pressure until the voltage output from the transducer 7 exactly matches the voltage output from the potentiometer 17; the error signal supplied by the comparator 18 is then zero and the servo-motor 4 stops. This is the desired condition.

If the delivery pressure should be greater than that required, then the comparator 18 drives the amplifier 40 in the opposite polarity sense, causing the servo-motor 4 to close the engine throttle, until the desired condition is reached.

If now the water demand becomes so great that the pump inlet pressure drops below the value set at the potentiometer 14 the polarity of the output of the comparator 15 reverses and drives the amplifier 40 in such a direction as to reduce the voltage across the potentiometer 14. This has the effect of reducing the "required delivery pressure" set at the potentiometer 17 and thus the servo-motor 4 is energised to close the engine throttle and thereby decrease the delivery pressure progressively—until the pump inlet pressure has risen to the value set at the potentiometer 14. In this mode of operation, the system operates at "constant inlet pressure" and the system will revert to the "constant delivery pressure" mode of operation when the water demand no longer exceeds its supply.

It will be appreciated that in the system shown in Figure 1, it may also be necessary to stabilize the control feedback loops by the application of any of the known techniques for this purpose, for example by rate feedback of delivery pressure to the amplifier 44.

The control system shown in Figure 2 and embodying the invention is a continuous predictive one, wherein any delivery pressure error is measured and the necessary pump speed correction appropriate to the error is computed and applied so as to tend to cancel out the said error.

A pump 1 is driven by an internal combustion engine 3 via a transmission gear unit 2. The unit 2 may be omitted and the engine directly coupled to the pump.

The mechanical arrangement controlling the power of the engine 3 is controlled by a servo-motor 4 whose position is determined by its associated drive unit 5. The pump suction inlet is connected by piping to a pressure sensor unit 6. The delivery manifold of the pump is piped to another pressure sensor unit 7. The pressure sensor units are preferably protected from damage owing to excessively high pressures by the use of restrictors or pressure snubbers 10 and 12 and pressure relief valves 11 and 13. The pressure sensor units may also include sources of excitation, and amplification in order to activate the sensor if required and to increase the signal output to a level which is of an acceptable and usable form.

The pump speed is measured by a tachometer 8, which is shown fitted to the pump, but may equally be fitted to any suitable point on the engine 3 or transmission gear 2, providing the gear ratio of the transmission gear 2 is constant and known.

Depending on the type of tachometer used, the signal output therefrom may need modifying or buffering by a tachometer signal conditioning unit 9 to give a signal output corresponding to the pump speed and another signal output corresponding to the reciprocal of the pump speed over its working speed range.

There are two pressure setting potentiometers 14 and 17 which may be of a continuous or of a switched type. The potentiometer 14 sets the signal input to a comparison unit 15 and may be replaced by any suitable means of generating a variable pre-set fixed value signal to the comparison unit 15. The potentiometer 17 sets the signal input to a comparison unit 18, this signal corresponding to the required delivery pressure. One end of the element of the potentiometer 14 is connected to a substantially constant signal of a level equal to or greater than the level of the maximum inlet pressure comparison signal. The other end of the element of the potentiometer 14 is connected to a substantially constant signal of a level equal to or less than the minimum inlet pressure comparison signal. The end of the element of the potentiometer 17 corresponding to the minimum required delivery pressure is connected to a substantially constant signal of a level corresponding to a signal equal to or less than zero delivery pressure. The output signal of the inlet pressure sensor 6 and that of the potentiometer 14 are fed to the comparison unit 15.

If the inlet pressure falls near to or below the value corresponding to the signal from the potentiometer 14 then the output signal of the comparison unit 15, which is connected to the input of a controlled regulator unit 16, causes the latter to decrease its controlled energising signal output, the later being connected to the end of the element of the potentiometer 17 corresponding to maximum required delivery pressure, so that the normal defined signal level of the potentiometer 17 which is equal to or greater than that corresponding to the maximum required delivery pressure, is reduced.

The output signal from the potentiometer 17 is fed to a comparison unit 18, which is also fed by the signal output from the delivery pressure sensor unit 7. The output signal from the comparison unit 18 is a function of

the error in required delivery pressure and is fed to a multiplier unit 19, where it is multiplied by a function of the signal corresponding to the reciprocal of the pump speed produced by the tachometer signal conditioning unit 9.

The signal output of the multiplier unit 19 is fed to a proportional amplifier unit 21 and also to an integrator unit 20; the outputs of these two last-mentioned units are summed in a summing unit 22. The signal output of the summing unit 22, which is a function of the required pump speed to give a required delivery pressure, is compared with the signal corresponding to the actual pump speed by a comparison unit 23, and the signal output from the latter, which corresponds to a function of the error in pump speed (i.e. the difference between the speed computer to be required to provide the required delivery pressure and the actual speed) is fed to the servomotor drive unit 5, which controls the servomotor 4, the latter actuating the speed control mechanism (e.g. the throttle, governor linkage or the like) of the engine 3.

In normal operation—the operation will be described, for convenience and by way of example only, with reference to electronic analog signals—with an unrestricted water supply the output signal from the inlet pressure sensor unit 6 is greater than that set on the potentiometer 14, so that the output of the comparison unit 15 drives the regulator unit 16 to deliver its maximum defined energising signal output to the maximum pressure end of the potentiometer 17.

If the pump delivery pressure is lower than the required pressure pre-set at the potentiometer 17, the signal output of the delivery pressure sensor unit 7 will be less than the output signal of the potentiometer 17. This will cause an error signal to be generated by the comparison unit 18 in the form of a difference between functions of the respective input signals to this unit. This error signal is processed by the multiplier unit 19, whose output signal is a product of functions of input signals thereto derived from the said comparison unit 18 and the pump tachometer unit 8 via the pump tachometer signal conditioning unit 9; the output signal from the multiplier unit 19 is further processed by the integrator unit 20, proportional amplifier unit 21 (in parallel with the latter) and the signal summing unit or summing amplifier 22, whose output signal is the sum of functions of the output signals from the units 20 and 21. The output signal from the unit 22, representing a processed delivery pressure error signal is compared with the pump speed signal derived from the tachometer conditioning unit 9 in the signal comparison unit 23; the output signal from the latter is the difference between functions of its input signals and is of such a polarity as to require, in the circumstances mentioned, an increase in pump speed so as to reduce the error in delivery pressure.

The purpose of the multiplier unit 19 is to retain a substantially constant system loop gain over the working speed range of the pump. Since in this particular embodiment of the invention the pump is a centrifugal pump, the pressure developed across the pump by its rotation is (for small flow rates) substantially proportional to the square of the pump shaft rotational speed, and, since the output from the unit 9 corresponds to the reciprocal of pump speed, the multiplier unit 19 causes a signal representing pressure error to be divided by one representing pump speed and thus corrects the pressure error signal to ensure a substantially constant system loop gain over the working range of the pump system. This can be seen from the theoretical centrifugal pump equation which states that the pressure P developed across the pump is substantially proportional to the square of the rate of rotation of the pump impeller ω less any losses L occurring within the pump system. The losses L are a function of the parameters of the pump, including the rate of fluid flow. Hence

$$P=a\omega^2-bL$$

where a and b are constants.

Thus for small errors in P,

$$\frac{dP}{d\omega}=2a\omega-\frac{d}{d\omega}(bL)$$

Thus, to keep

$$\frac{dP}{d\omega}$$

constant, and hence constant loop gain with varying speeds, and neglecting the term

$$\frac{d}{d\omega}(bL)$$

any error in P fed in as a speed correction must preferably have a multiplier term $1/2a\omega$ contained within the pressure error signal processing chain.

The units 20, 21 and 22 effectively define a process controller having proportional and integral re-set functions, which tend to reduce the final pressure error substantially to zero, the output of the summing amplifier unit 22 being a time dependent corrected function of the error in required delivery pressure in a form suitable for correcting the pump speed.

As the pump speed increases to a value corresponding more closely to the required

delivery pressure set at the potentiometer 17, the action of the integrator unit 20 finally causes the delivery pressure error to become substantially zero. It should, however, be noted, that whilst the integrator unit 20 improves the overall accuracy of control, it is not essential.

If the delivery pressure exceeds the required delivery pressure pre-set at the potentiometer 17, the reverse situation from that just described arises and the pump speed is progressively reduced until the delivery pressure error is once again substantially zero.

The above-mentioned constants and the mathematical functions generated by the units 18, 19, 21, 22 and 23 are so chosen that the equation

$$P=a\omega^2$$

is substantially obeyed for small errors in P. The system will then be of the continuous predictive type, whereby any delivery pressure error is measured and the necessary pump speed correction computed and then applied so as to tend to reduce this error.

If the water supply to the pump is insufficient, such that the suction inlet pressure falls to a value such that the output signal from the inlet pressure sensor unit 6 falls near to or below the signal level set on the potentiometer 14, the overall operation of the system changes from one operating to give a constant desired delivery pressure to one where the delivery pressure is reduced sufficiently to prevent the inlet pressure falling to an unacceptably low value. This is about 0 psi gauge for soft suction hose and about 3 to 8 psi absolute pressure for hard suction hose.

The comparison unit 15 detects that the inlet sensor unit 6 has an output signal near to or below the output signal from the potentiometer 14, and its output signal alters so as to cause the controlled regulator unit 16 to decrease its signal energisation of the potentiometer 17. As a direct consequence, the "required delivery pressure" signal output from the potentiometer 17 is reduced to a lower value, causing a reduction in pump speed and in the actual pump delivery pressure. Consequently the water flow rate will be reduced and the low inlet pressure condition alleviated.

A condition of equilibrium will be reached where the pump is delivering water at a pressure as near to the required value as possible, but such that the inlet pressure does not drop below the pre-set level which is primarily determined by the notentiometer 14.

The gain and level constants of the comparison unit 15 and the regulator unit 16 are preferably such that at the minimum acceptable inlet pressure the effective energising signal across the potentiometer 17 is zero. This corresponds to a required delivery pressure of zero, and for soft suction hose the prime mover speed will drop to "tick-over".

In the modified system shown in Figure 3, the components which are identical to those shown in Figure 2 are identified by the same reference numerals.

In this modified system, however, the units 6, 14 and 15 are replaced by pressure switches 30, 31, manually operable switch unit 32 and a signal conditioning unit 33.

Depending on whether the inlet hose to the pump is of the "soft" (i.e. collapsible) or of the "hard" (i.e. rigid) kind, the pump operator sets the switch unit 32 either to "hard suction" or to "soft suction", thereby switching the appropriate one of the pressure switches 30, 31 into the control system.

The pressure switch 30 (intended for "hard suction") is set to close at a pump inlet pressure which is high enough for the pump speed to be safely increased without causing cavitation in the pump. It opens when the inlet pressure drops to a level at which cavitation, or excessive cavitation would occur.

The pressure switch 31 (for "soft suction") is set to open if the inlet pressure drops to, or near to, atmospheric pressure, so as to prevent collapse of the soft suction hose. The switch 31 closes on an increasing inlet pressure when the pump speed may safely be increased without danger of the hose collapsing.

The signal conditioning unit 33 has an output signal which is a function of the input signal such that the controlled regulator unit 16 is caused to deliver its maximum defined output signal to the potentiometer 17 for so long as the switch 30 or 31 which is in use is closed, i.e. so long as the inlet pressure is at or above the acceptable minimum value. If the inlet pressure switch 30 or 31 in use should open, indicating that the inlet pressure is becoming too low, the signal conditioning unit 33 will detect this and cause the drive to the regulator unit 16 to be such that its output signal to the potentiometer 17 is reduced, thereby reducing the pump speed in the manner described with reference to Figure 2.

When operating with a restricted water supply, the pump delivery pressure will cycle continuously as the said pressure switch 30 or 31 closes and opens.

Although satisfactory for some applications, this mode of operation represents, as will be appreciated, a distinct degradation of performance as compared with that of the system shown in Figure 2.

In the further modification of the system of Figure 2 shown in Figure 4, the components common to the two forms of system are again identified by the same reference numerals.

In this modified system, however, the units 6, 14 and 15 are replaced by pressure operated switches 34, 35, supplied by a positive

and a negative voltage supply 37, 38 respectively and connected via resistors 39, 40 respectively to an integrator unit 36.

The same switches 34, 35 may, if their settings are variable, be used by altering their settings for both "soft suction" and "hard suction" conditions, or alternatively one pair of switches such as 34, 35 may be provided for each of these conditions together with a manual switch unit such as that indicated by 32 in Figure 3.

In the system shown, if the water supply is insufficient, a pump delivery pressure will be maintained so long as the pump inlet pressure does not fall below the contact closing pressure of the switch 34 and the contact opening pressure of the switch 35, the switches being, as in the system shown in Figure 3, responsive to pump inlet pressure.

For "soft suction", the switch 34 is set to close on decreasing inlet pressure at, say, 5 psi gauge and opens again on increasing inlet pressure at, say, 7 psi gauge. The switch 35 must close its contacts at a pressure greater than the closing contact pressure of the switch 34 and is set to open its contacts on decreasing inlet pressure at, say, 8 psi gauge and to close its contacts on increasing inlet pressure at, say, 10 psi gauge.

For "hard suction" the same conditions apply except that the pressures are now probably sub-atmospheric and the control is designed to prevent or reduce cavitation in the pump.

The system operates substantially as hereinbefore described with reference to Figure 2, so long as the water supply is unrestricted, viz. so long as the inlet pressure does not drop below the value at which the contacts of the switch 35 open. When these contacts open, the input to the integrator unit 36 becomes zero and its output signal does not change. When the inlet pressure drops still further, viz. to a value at which the contacts of the switch 34 close, the input signal to the integrator unit 36 causes its output signal to fall; consequently the output signal from the regulator unit 16 falls and the pump speed is continuously reduced in the manner described with reference to Figure 2, until the inlet pressure rises to a level at which the contacts of the switch 34 open. The input signal to the integrator unit 36 is then again zero and the pump speed remains nominally constant.

If now the water supply to the pump is sufficient such that the inlet pressure rises to a value at which the contacts of the switch 35 close, current will be drawn out of the integrator unit 36 input and its output signal will increase causing (via the regulator unit 16) the voltage across the potentiometer 17 to increase, whereby the pump speed is increased in the manner previously described until normal operation, at which the pump delivers water at a substantially constant delivery pressure, is again resumed.

This form of system is thus better than that shown in Figure 3 because the delivery pressure does not continuously cycle, but has a "dead" band of inlet pressure variation in which operation is acceptable.

In a further modified system, in which one or both of the inlet and delivery pressure sensing units 6, 7 are replaced by an arrangement of pressure switches, such an arrangement may be as shown in Figure 5 which, by way of example, shows only a typical such switch arrangement for delivery pressure sensing; the corresponding arrangement for inlet pressure sensing would be substantially the same.

The switch arrangement comprises pressure operated switches 25 to 28 connected respectively to resistors 41 to 44, a constant voltage supply 45 therefor, a reference current source 29 and a current summing unit 24.

In the example, the switches 25 to 28, which are responsive to different discrete nominal pressures, are electric switches whose contacts close when they are subjected to the respective said nominal pressures. Such switches usually have hysteresis and will not open again until the pressure has dropped appreciably below their operating pressure. This characteristic presents a degradation in overall performance.

As each switch 25 to 28 closes, it adds (or subtracts) a predetermined amount of current for use as the input signal to the signal comparison unit 18, these currents first being summed in the current summing unit 24.

It may be necessary to interpose a filter or an integrator to smooth the changes in the input signal to the comparison unit 18 between the latter and the summing unit 24.

The number of switches such as 25 to 28 provided depends on the degree of accuracy required. In an extreme case this number could be one. The pump operator could alter the pump operating conditions, i.e. the required delivery pressure and/or the minimum acceptable inlet pressure, by altering the operating level(s) of the switch(es).

If the arrangement of pressure switches described is applied to the pump inlet pressure, as hereinbefore mentioned, the output signal from the current summing unit 34 would be fed to the signal regulator unit 16 (Figure 2) instead of the unit 18.

Figure 6, in which so far as relevant the same reference numerals are used as in the other figures, gives a general indication of some of the various forms which the control system in accordance with the invention may take and the manner in which it may be applied to a variety of fluid pump units.

As will be apparent from the description which follows, some of the integers shown in Figure 6 (such as the tachometers 8, 8'

and the servo-motors 4, 4') are shown in alternative positions.

In Figure 6, the prime mover 3 could, for example, be an internal combustion engine (such as a petrol or diesel engine or a gas turbine), an external combustion engine (such as a steam engine or turbine), an electric motor (in which case a servo-motor as such to control the power output of the motor need not be necessary), a hydraulic or pneumatic motor or a water turbine.

The transmission between the prime mover and the pump may take the form of simply a shaft 41 therebetween, a fixed single ratio gearbox, a multi fixed-ratio gearbox (as may typically be found fitted to road vehicles), a continuously variable gearbox with or without discontinuities in the ratio range (in which case the ratio may or may not be externally controlled and may be controlled by the speed or power or both transmitted by the gearbox), a continuously variable gearbox 2 with provision (in the form of a servo-motor 4') to vary the ratio externally as a means of controlling the pump speed, any combination of the forgeing, any of the foregoing forms including a clutch (e.g. to disconnect the prime mover 3 from the pump 1) or any of the foregoing forms with facilities to drive other loads in addition or alternatively to the pump.

The pump itself could, for example, take the form of a single or multi-stage centrifugal pump (or turbine pump) commonly used in fire appliances for pumping water, or a positive displacement pump with or without means for varying the displacement per stroke or per revolution of the pump (in which latter case the displacement may also be used as a means of controlling the system in the manner hereinbefore described).

The pressure sensors 6, 7 are piped to sense the pressures present at suitable points in the pump inlet and pump delivery manifold 42 and 43 respectively. Preferably they have a signal output which is substantially proportional to the pressure, or which is a continuous function of the pressure within their operating limits.

However, as has already been described with reference to Figures 3 to 5, it is possible to use pressure operated switches operating at discrete pressures to provide in effect the actual and reference values of pressure and a comparison therebetween. In an extreme case one switch only per sensing point could be used, but in that event the final degree of control achieved would be considerably degraded. An acceptable compromise might be found by the use of a continuous type, sensor connected to the pump delivery manifold, and one or more pressure operated switches connected to the pump inlet as hereinbefore described.

Since pressure sensors may be damaged, or their calibration altered, if subjected to a pressure in excess of their rated maximum over-pressure limit and, particularly when used on a fire appliance pump, the over-pressure surges and spikes are virtually impossible to predict accurately, the sensors (whether of the potentiometric or switch type as hereinbefore described) must be of rugged construction and should preferably be protected against such over-pressures. The preferred method of protection is to use a combination of a flow restrictor (sometime referred to as a "pressure snubber") and an over-pressure relief valve 10/11 and 12/13 respectively in the pipe work connecting the sensor to the point of measurement.

Pumps used for fire fighting purposes are usually of the centrifugal or turbine type, and hence in such cases the tachometer 8 is used to measure the speed of rotation of the pump impeller. The tachometer may be connected to any suitable point at or between the pump and the prime mover if the transmission gear therebetween is of a constant fixed ratio when pumping; otherwise if the transmission gear has a variable unknown ratio, the tachometer must be connected at or between the pump and the transmission gear.

A tachometer 8' on the prime mover is rarely necessary, but if the transmission gear between it and the pump has a variable characteristic, it may be required for the purpose of calculating the absolute speed of the prime mover and its relative speed to the pump in order to provide the pump control system with the necessary information to optimise the system constants for good stability and speed of response. It may also be required to detect overspeeding of the prime mover and to remedy this situation,-for example, by decreasing the power supplied to the prime mover. The pump tachometer 8 may also, for a known transmission gear ratio, be used to protect the system from overspeeding in similar fashion.

In Figure 6, two servo-motors 4, 4' are shown controlling mechanical control linkages of the prime mover 3 and the transmission gear 2 between it and the pump respectively. Three positions are, however, possible and normally only one is used. Thus, if the transmission ratio is fixed (or, if variable, not amenable to direct control) the power or speed of the prime mover 3 is preferably under the control by its associated servo-motor 4. In some cases, for example in the case of an electric driving motor, the controlling servo-motor may be eliminated and the prime mover directly controlled by the output signal from the control system.

The second of the three positions mentioned may be used where the prime mover 3 runs at substantially constant speed, for example in the case of a governor controlled diesel engine, and the pump speed is controlled by variation of the transmission ratio between

it and pump 1 using a servo-motor 4′ associated with the transmission gear. As in the case of the first position mentioned, it may be possible to dispense with the servo-motor 4′ and to use a direct acting system output signal to control the gear ratio.

In the third of the positions referred to, e.g. where the pump is of the variable displacement type, the servo-motor may be arranged to control the magnitude of the displacement per stroke or per revolution of the pump. In this case the pump will probably be arranged to run at constant speed.

In the form of control system described with reference to Figure 2, the pressure reference means 14 and 17 are in the form of electric potentiometers and therefore require to be fed with electrical analog type signals. However, by replacing the potentiometer 14 with a variable pre-set signal generator and the potentiometer 17 with a variable pre-set signal dividing device, the signals concerned may take one of a variety of forms and may, for example, be of the modulated or digital electronic form, or they may be pneumatic, hydraulic, or mechanical signals.

Accordingly also, whilst the practical electronic realisation of the various measurement, comparison, integrating and other computing units is preferably effected by the application of conventional analog or digital computer techniques (as is implied in the foregoing description of the system) it may also be effected by any other known form of electronic modulation apparatus, and equivalent functions can also be realised by hydraulic, pneumatic or mechanical means or any suitable combination of any of these means.

It will also be appreciated that, since closed loop automatic control systems are prone to instability, one or more forms of stabilisation may be required in the present system to ensure a stable non-oscillatory system. For this purpose any of the conventional techniques of system stabilisation may be required and applied, such as the use of time dependent functions of any of the signals present in the system or generated especially for the purpose. In particular, since identical hydraulic operating conditions for the pump are rarely encountered in fire appliances, self-adaptive stabilisation techniques for optimising the system response in any pumping conditions should be considered for such application.

The form of system described with reference to Figure 2 may, apart from the modifications already described with reference to Figures 3 to 5 and otherwise, be further modified in other respects, of which the following are also given by way of example:

Referring further to Figure 2, the maximum pressure end of the element of the potentiometer 17 may be taken to a substantially constant signal level equal to or greater than that corresponding to the maximum required delivery pressure and the regulator unit 16 omitted. In this case the output signal of the comparison unit 15 and that of the potentiometer 17 would be fed into a subtractor unit in which the output signal of the comparison unit 15 is subtracted from the "set required delivery pressure" signal from the potentiometer 17. The output signal of this additional subtractor unit would be fed to the "x" signal input of the comparison unit 18 in Figure 2. In this case, in normal unrestricted water supply situations, the output of the comparison unit 15 is at a fixed defined level substantially equivalent to zero, so that the output of the potentiometer 17 is unchanged and the control system operates as hereinbefore described. If the water supply is insufficient such that the output signal of the inlet pressure sensor unit 6 falls near to or below that set on the potentiometer 14, then the output of the comparison unit 15 is altered such that the signal which it feeds to the additional subtractor unit is subtracted from the output signal of the potentiometer 17, and consequently the input signal to the comparison unit 18 corresponds to a reduced "required delivery pressure". Hence, the system again changes from one controlling "constant delivery pressure" to one controlling "minimum inlet" for so long as the water supply is inadequate to meet the operational demand of the pump.

Another modification of the system as shown in Figure 2 and representing a refinement thereof would be to feed into the summing unit 22 a further signal for summation, being a signal computed equivalent to the pump speed required, for example a signal substantially proportional to the square root of the difference between the "required delivery pressure" signal from the potentiometer 17 and the signal corresponding to the inlet pressure from the inlet sensor unit 6. The proportional constant is $1/\sqrt{a}$ derived from the basic equation for a centrifugal pump

$$P=a\omega^2-bL$$

where the symbols have the values and meanings hereinbefore defined.

In yet another modification, if the prime mover is already fitted with a speed governer adequate for the purpose, the comparison unit 23 could be omitted and the output signal of the summing unit 22 connected direct to the input of the servo-motor drive unit 5, which in turn controls the existing speed governor setting.

As shown in Figure 6, the servo-motor 4 (Figure 2) can be used to control the speed ratio of a transmission gear between the prime mover and the pump. In this case the prime mover would probably run at substantially constant speed either inherently or under the control of a separate speed governor.

If desired, any of the forms of control system hereinbefore described and the possible modifications thereof which have been outlined could also be made responsive to cavitation in the pump, the onset of which is usually accompanied by a distinctive type of rattling sound which could, for example, be detected by a mechanical vibration or accoustic sensor.

Thus, if such a sensor were to detect cavitation, its output could be used to influence the servo-motor 4 to adjust the delivery pressure to the pump by reducing the pump speed to a point where the noise of cavitation was acceptable,, viz. the vibration and/or sound are within predetermined acceptable limits. The sensor output could be of a continuous type—proportional or otherwise continuously related to the amount of caviation—or it could be switched like a pressure operated switch, in which latter case any of the techniques described in relation to the pressure responsive switches with reference to any one of Figure 3, 4 and 5 could be used. Cavitation responsive pump control would, however, generally be employed only in cases where sub-atmospheric pressures were present at the suction inlet to the pump, so that this technique would probably not be of much value where "soft" suction is in used.

As will be apparent to those skilled in the art, fluid pumps other than of the centrifugal kind do not necessarily obey the equations hereinbefore specified. Thus, for example, in the case of a positive displacement pump, quite different pressure error signal processing from that described would have to be employed to obtain the required correction signal, but without departing from the scope of the invention.

WHAT I CLAIM IS:—

1. A fluid pump unit control system comprising first fluid pressure responsive means for comparing a first fluid pressure with a first reference value thereof and to provide a first signal representing a deviation of the said first fluid pressure from the said first reference value, second fluid pressure responsive means for comparing a second fluid pressure with a second reference value thereof to provide a second signal representing a deviation of the said second fluid pressure from the said second reference value and defining a component of a system output signal, and a regulating device responsive to the said output signal, and tending to maintain the said second fluid pressure at the said second reference value, the said first and second fluid pressure responsive means being so connected that the said second reference value depends on the said deviation of the first fluid pressure.

2. A system according to Claim 1, wherein the said first and second fluid pressure responsive means each comprise a pressure sensor in the form of a pressure-responsive transducer arranged to produce electrical signals representing the pressure sensed by the sensor.

3. A system according to Claim 2, wherein the said first and second signals are in the form of voltages.

4. A system according to any one of the preceding claims, wherein the said first reference value is defined by a predeterminable and adjustable first set point of the said first fluid pressure responsive means and the said second fluid pressure responsive means has an adjustable second set point for defining the first fluid pressure dependent second reference value.

5. A system according to any one of the preceding claims, wherein the said first and second fluid pressure responsive means each comprise a comparator for comparing the said first and second fluid pressure with the said first and second reference value thereof respectively, the output signals from the comparator of the said second fluid pressure responsive means defining the said system output signal or component thereof, the said regulating device being defined by a speed controller for controlling the speed of a pump drive and having a servo-motor connected to receive the system output signal, and the comparator of the said second fluid pressure responsive means having an input such as to make its output dependent upon the output of the comparator of the said first fluid pressure responsive means.

6. A system according to any one of the preceding claims, wherein at least one of the said first and second fluid pressure responsive means is protected from damage owing to excessively high pressures by a pressure snubber and/or a pressure relief valve.

7. A system according to any one of the preceding claims, wherein at least one of the said first and second fluid pressure responsive means includes a source of excitation for activating the said fluid pressure responsive means if required, and/or amplifying means to increase the said first and/or second signal as the case may be to an acceptable and usable level.

8. A system according to any one of the preceding claims, including a tachometer for operative connection to the pump or the pump drive of the fluid pump unit and a tachometer signal conditioning unit to provide a speed signal corresponding to the speed of the pump or drive, as the case may be, and also a time signal corresponding to the reciprocal of the said pump or drivé speed, as the case may be, over its working speed range.

9. A system according to Claim 8, wherein a multiplier unit is connected to provide a ratio signal representing the product of the said second signal and the said time signal.

10. A system according to Claim 9, wherein an integrator unit and a proportional amplifier unit are each connected to receive the said ratio signal and a signal summing unit is connected to receive the outputs from the said integrator unit and proportional amplifier unit.

11. A system according to Claim 10, wherein a signal comparison unit is connected to receive the output from the said signal summing unit and an output from the said tachometer signal conditioning unit to provide the said system output signal which corresponds to a function of the error in pump speed and is supplied to the said regulating device.

12. A system according to Claim 5 and any one of Claims 8 to 11, modified in that the said first fluid pressure responsive means comprises a pressure sensor in the form of a fluid pressure responsive switch arranged or adapted to become actuated at a predeterminable pressure and, in lieu of the said comparator, a signal conditioning unit connected to receive the output from the said pressure sensor and, via a controlled regulator unit, to supply a maximum defined output signal to the said second fluid pressure responsive means so long as the said pressure responsive switch is actuated by the said first fluid pressure.

13. A system according to Claim 5 and any one of Claims 8 to 11, modified in that the said first fluid pressure responsive means comprises a pressure sensor in the form of a first and a second fluid pressure responsive switch, a manually operable switch unit connected to connect either the said first or the said second pressure responsive switch in the system and, in lieu of the said comparator, a signal conditioning unit connected to receive the output from the said pressure sensor and, via a controlled regulator unit, to supply a maximum defined output signal to the said second fluid pressure responsive means so long as the said first or the said second pressure responsive switch which is connected in the system is actuated by the said first fluid pressure, the said first and second fluid pressure responsive switches being arranged or adapted to become actuated at different predeterminable pressures.

14. A system according to Claim 5 and any one of Claims 8 to 11, modified in that the said first fluid pressure responsive means comprises a pressure sensor in the form of a first and a second fluid pressure responsive electric switch arranged or adapted to become actuated at different predeterminable pressures and respectively to be supplied by a positive and a negative voltage supply, an integrator unit connected to receive the output from the said pressure sensor and, via a controlled regulator unit, to supply a signal to the said second fluid pressure responsive means depending upon the said predeterminable pressures and the fluid pressure acting on the said switches.

15. A system according to Claim 5 and any one of Claims 8 to 11, modified in that the said first fluid pressure responsive means comprises a pressure sensor in the form of a first and a second set of a first and a second fluid pressure responsive electric switch each, the said switches being arranged or adapted to become actuated at different predeterminable pressures, a manually operable switch unit connected to connect either the said first or the said second set in the system and, in lieu of the said comparator, an integrator unit connected to receive the output from the said pressure sensor and, via a controlled regulator unit, to supply a signal to the said second fluid pressure responsive means depending upon the said predeterminable pressures, the setting of the said manually operable switch unit and the fluid pressure acting on the said switches.

16. A system according to any one of Claims 12 to 15, wherein the said predeterminable pressure or pressures acting on the said switch or switches is or are adjustable.

17. A system according to Claim 5 and any one of Claims 8 to 11, modified in that at least the said first fluid pressure responsive means or the said second fluid pressure responsive means comprises a pressure sensor in the form of a plurality of fluid pressure responsive electric switches, arranged or adapted to become actuated at different predeterminable pressures, and an electric current summing units connected to receive the outputs from the said switches and to supply an output signal to the comparator of the said first fluid pressure responsive means or, as the case may be, the said second fluid pressure responsive means, the arrangement being such that as each of the said switches becomes actuated, it adds to, or subtracts from, the input to the said current summing unit a predetermined current.

18. A system according to Claim 11, wherein the said summing unit is arranged to be supplied by a further signal for summation, the said further signal being substantially proportional to the square root of the difference between the said second reference value and the said first fluid pressure.

19. A system according to any one of the preceding claims, including a mechanical vibration or acoustic sensor arranged to emit a signal representing vibration or sound attributable to a threshold condition of the said second fluid pressure and connected to influence the said regulating device in such a way as to adjust the said second fluid pressure to a value at which the said vibration and/or sound is/are kept within predetermined acceptable limits.

20. A system according to any one of Claims 6 to 19, wherein, in a first mode of opera-

tion of the system, the said first reference value is predeterminable and the said second reference value is predeterminable when the said first fluid pressure has a value at least equal to the said first reference value and, in a second mode of operation of the system, the said second reference value is determined by the value of the said first fluid pressure when this value is below the said first reference value, whereby in the said first mode the regulating device tends to maintain the said second fluid pressure at the said predeterminable reference value thereof and in the said second mode the regulating device tends to restore the said first fluid pressure to at least the said first reference value.

21. A fluid pump unit control system constructed, arranged and adapted to operate substantially as hereinbefore described with reference to, and as illustrated in, Figure 2 with or without the modification of Figure 5, or Figure 3 or Figure 4 of the accompanying diagrammatic drawings.

22. A fluid pump unit comprising a fluid pump and a drive for the pump and having a control system according to any one of the preceding claims, wherein the said first fluid pressure is defined by the pump inlet pressure, the said second fluid pressure is defined by the pump delivery pressure and the said regulating device is defined by a device for varying a pump parameter which affects the pump delivery pressure.

23. A fluid pump unit according to Claim 22, wherein the said pump drive is defined by an internal combustion engine and the said regulating device is arranged to control the throttle opening of the engine.

24. A fluid pump unit according to Claim 22, wherein the said regulating device is arranged to control the transmission ratio of a transmission gear of the pump unit drive arranged between a prime mover of the drive and the pump.

25. A fluid pump unit according to any one of Claims 22 to 24, wherein a component of the system output signal is defined by a speed signal derived from a tachometer connected to monitor the speed of the pump.

26. A fluid pump unit according to any one of Claims 22 to 24, wherein a component of the system output signal is defined by a speed signal derived from a tachometer connected to monitor the speed of the or a prime mover of the unit drive.

27. A fluid pump unit according to any one of Claims 22 to 26 and having a control system according to Claim 19, wherein the said sound is that produced by cavitation.

28. A fluid pump unit constructed, arranged and adapted to operate substantially as hereinbefore described with reference to, and as illustrated in, Figure 6 in combination with any one of Figure 2 with or without the modification of Figure 5, Figure 3 and Figure 4 of the accompanying diagrammatic drawings.

29. A fire fighting applicance including a fluid pump unit according to any one of Claims 22 to 28, wherein the said fluid pump is defined by a water pump and the unit is adapted for use with a "soft" (i.e. collapsible) and/or "hard" (i.e. rigid) inlet hose.

SAUNDERS & DOLLEYMORE,
Chartered Patent Agents,
2a Main Avenue,
Moor Park,
Northwood,
Middx. HA6 2HJ.
For the Applicant.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1976.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

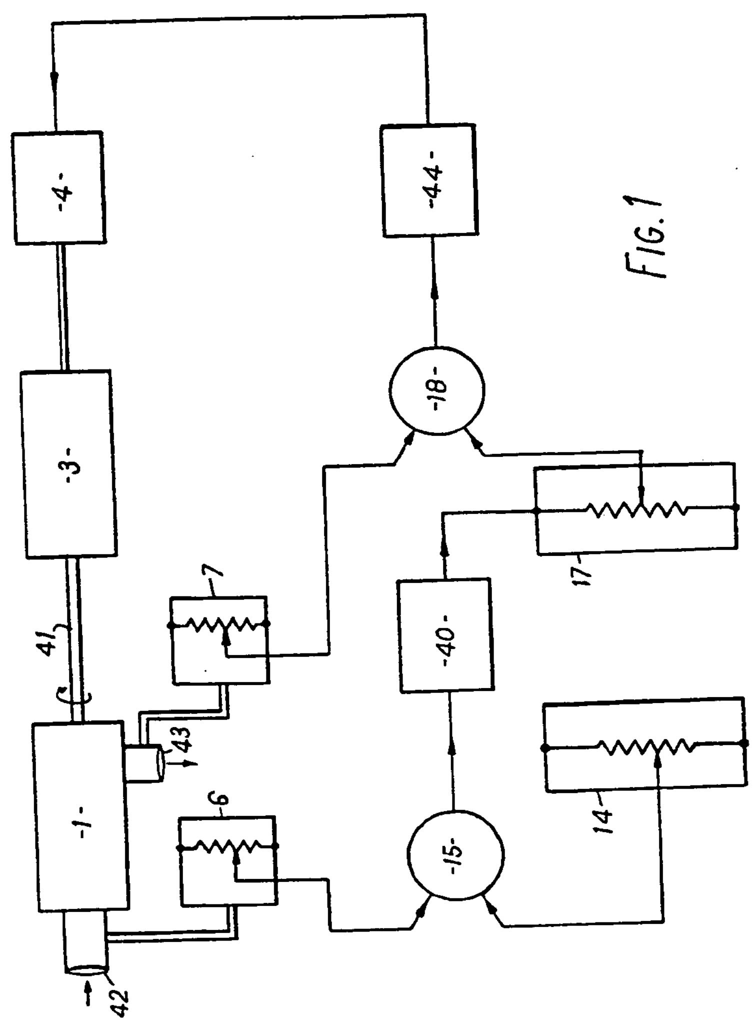


FIG. 1

1449852 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

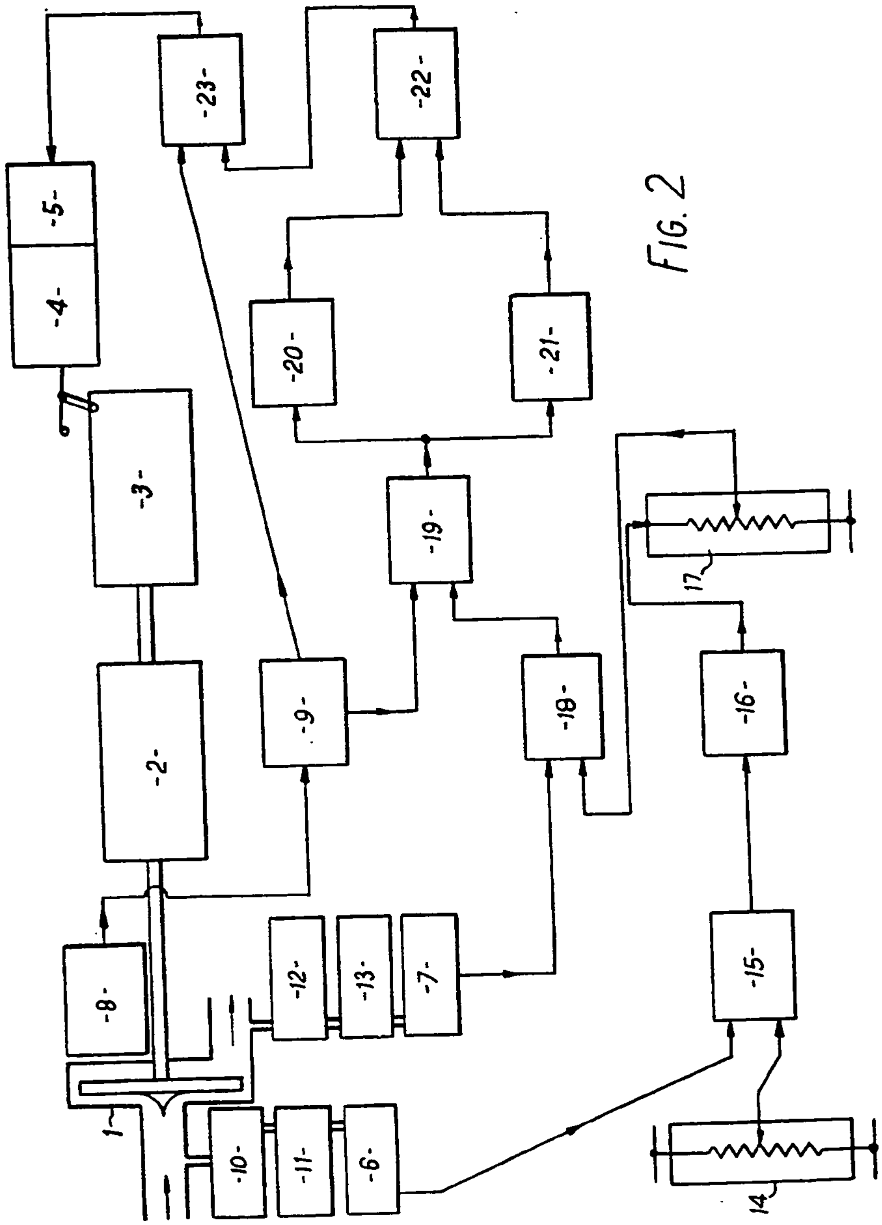


FIG. 2

1449852 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

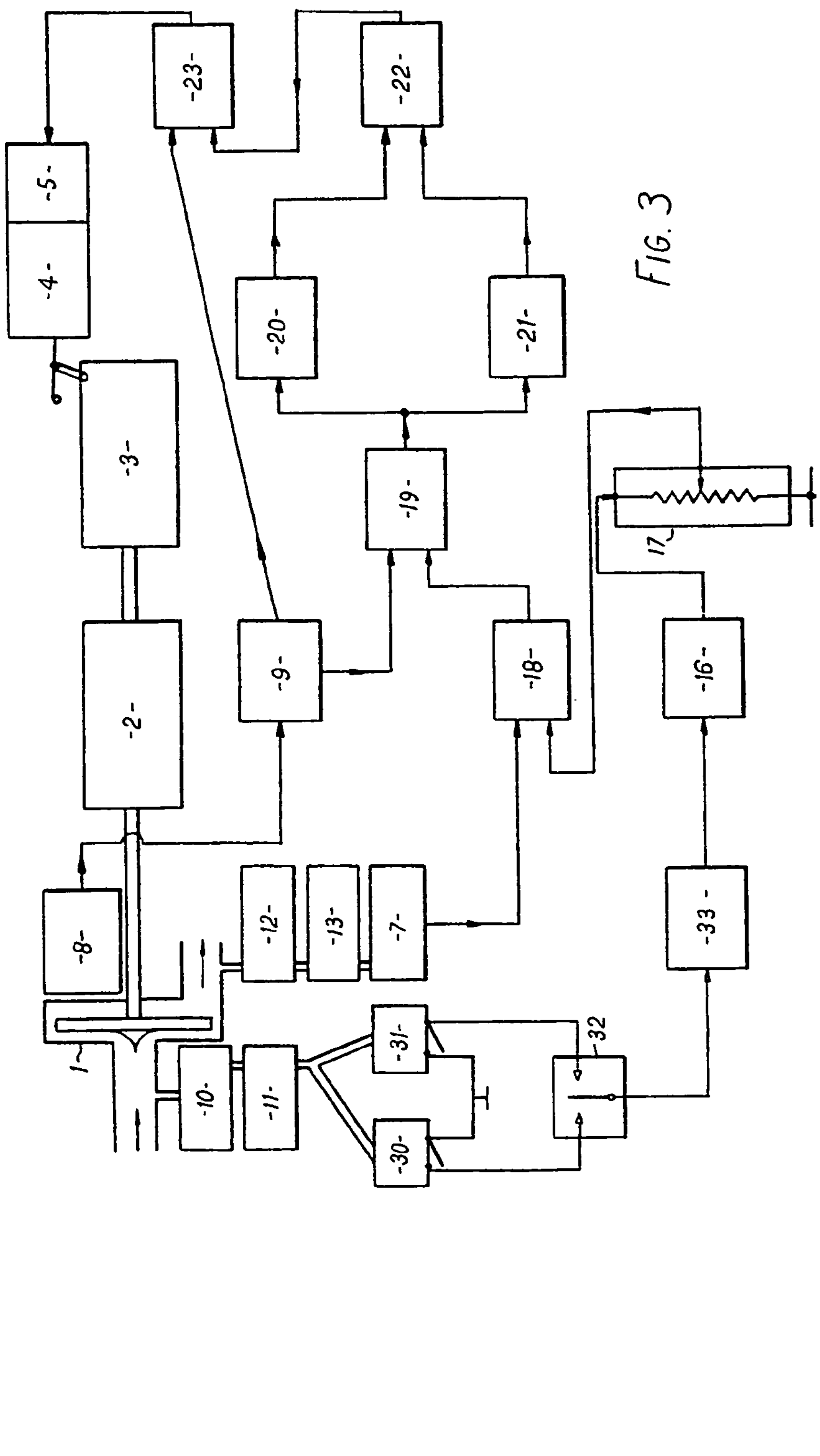


FIG. 3

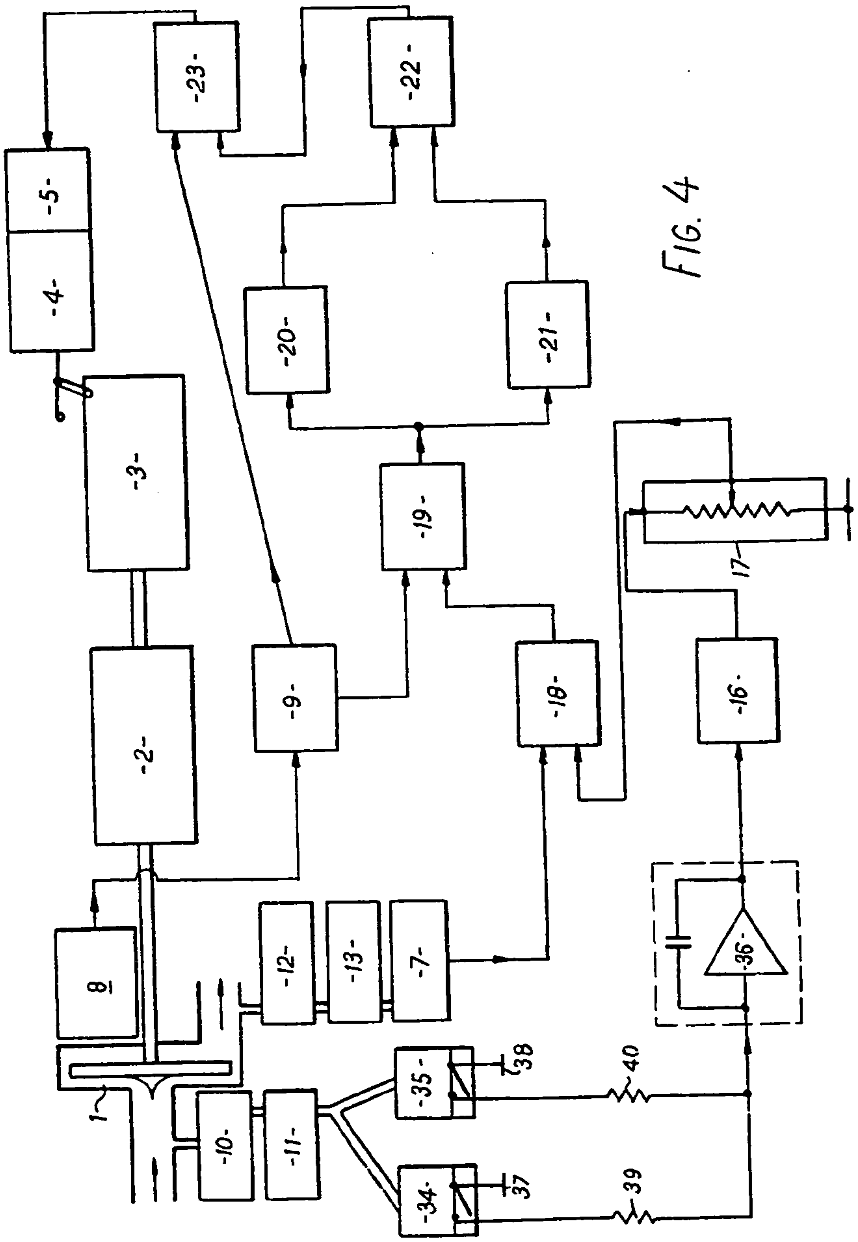
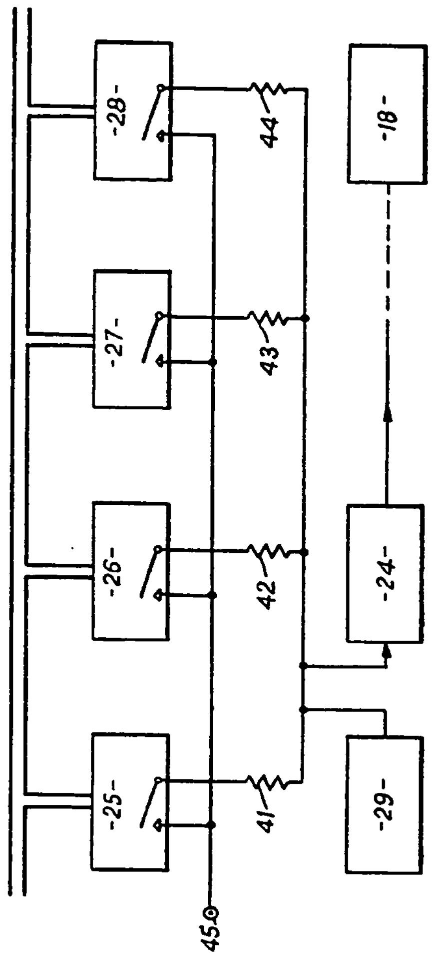


FIG. 4

FIG. 5



1449852 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

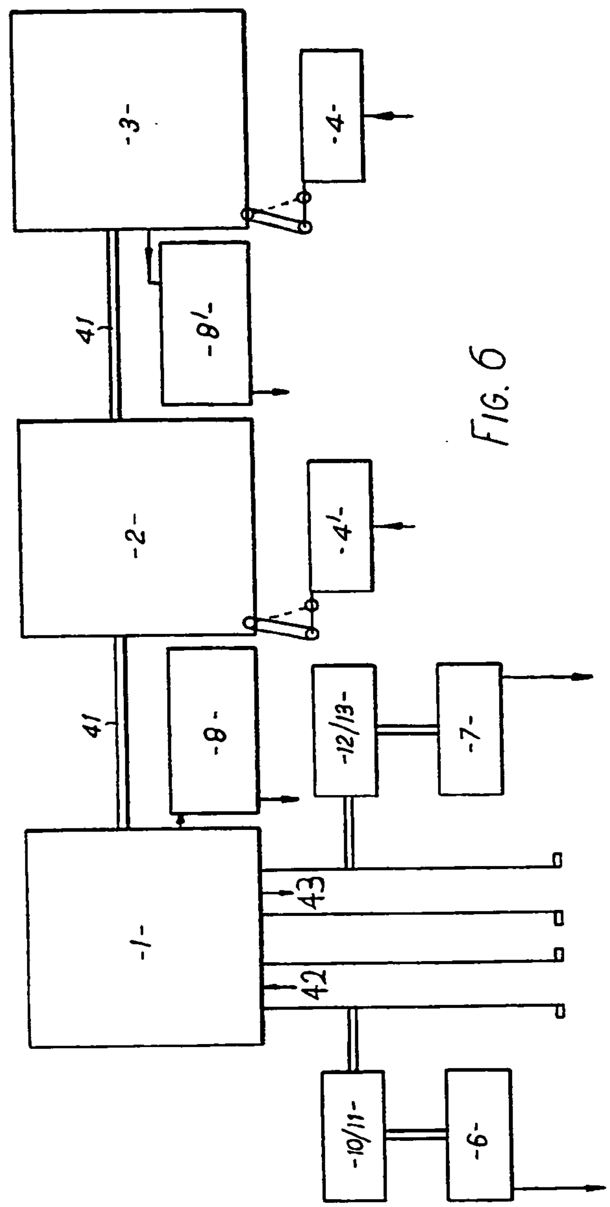


FIG. 6